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AUTOMATIC CONTROL OF SEED COTTON DRYING AT COTTON GINS, A REVIEW OF RESEARCH

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BACKGROUND

Virtually every cotton gin in the United States includes one or more driers for conditioning incoming cotton as a part of the ginning process. Cottons containing more than a certain level of moisture will cling together as wads, causing machinery chokage or breakdown. If such cotton does get through the system, it will gin poorly and give a rough lint preparation appearance that carries severe price penalties on the market. On the other hand, cottons that have been dried to low moisture levels and subjected to an elaborate machinery setup process smoothly through the gin plant and yield maximum lint grades. However, a noticeable reduction in staple length and length uniformity and an increased quantity of short fiber occur. The spinning industry states that cottons with reduction in length uniformity are the poor performers.

In 1947 an exploratory test was run to compare fiber and spinning qualities of lint dried and ginned immediately with those of lint dried but allowed to regain moisture before ginning. This test showed that cotton ginned in an overdried state was reduced in fiber and spinning qualities, and that cotton allowed to regain moisture prior to ginning retained, to a large degree, its normal fiber and spinning qualities.[2/]

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2/ "Moisture Content of Seed Cotton in Relation to Cleaning and Ginning Efficiency and Lint Quality," by A. C. Griffin, Jr., and C. M. Merkel, Production Marketing Administration and Agricultural Research Service, U. S. Department of Agriculture, September 1953.

An extensive series of seed cotton drying tests at Stoneville in 1949 and 1950 showed the following:

(1) The greater the moisture removal from increased drying, the higher the grade of the ginned lint.

(2) Fiber length and strength and yarn strength and appearance tended to lower with increased drying.

(3) Cottons dried to 4-percent fiber moisture for cleaning and ginning produced lint of somewhat inferior fiber and spinning quality to those dried and ginned in the 6.5 to 8 percent range.

(4) Fiber and spinning quality changes due to gin drying correlated better with fiber moisture content at the time of ginning than with drying air temperatures.

(5) Cottons dried to the 3-percent fiber moisture level using temperatures of 130°, 200°, and 300° F. exhibited remarkably similar fiber and spinning properties (table 1).

Table 1. Effects of seed cotton drying conditions on selected fiber and spinning quality elements.1/

Item		No drying	200° F. 10 min.	300° F. 5 min.	130° F. 60 min.
Lint moisture	pct.	8.2	3.3	3.2	3.0
Upper half mean length	in.	1.05	1.00	1.00	.99
Classer's staple	1/32-in.	34.6	34.2	34.3	34.0
Tensile strength	1,000 p.s.i.	77	77	77	75
Card web neps-per	100 sq. in.	43	47	46	57
Yarn break factor	22's	2310	2156	2156	2156
Yarn appearance		93	90	90	90

1/ Average of 3 replications machine-picked cotton, crop of 1950. Test 044.

These tests led to the conclusion that advice to ginners regarding cotton drying practices should be based on achieving a particular fiber moisture content at the gin stand. These same tests showed the need for a drier control system based on continuous moisture measurement rather than a set of recommended temperatures that could only prove unsatisfactory.

GIN DRYING SYSTEMS

In the typical gin for processing machine-picked cotton, there are two similar stages of drying--cleaning and extracting (Fig. 1). Each drying stage begins with a hot-air pickup and ends with a separating cleaner. Air velocity in the transport pipe is about 4,500 f.p.m. (feet per minute) through the drier itself the velocity is about 1,600 f.p.m. There is some slippage between cotton and air so that cotton in the drying system moves somewhat slower than the conveying air. Damp cotton is fluffed less than drier cotton and moves more slowly than well fluffed cotton for a given air velocity. In the gin at Stoneville in 1960 the average cotton exposure in each drying stage was 16 seconds for the first stage and 10 seconds for the second stage.

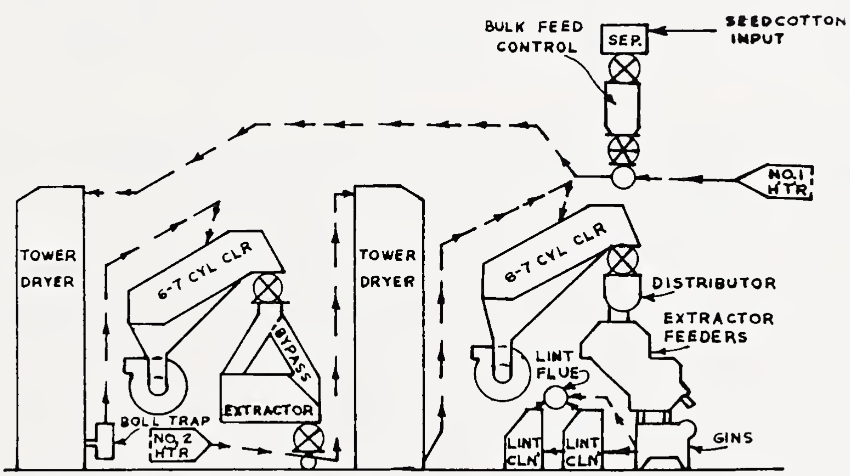


Figure 1. Typical gin for processing machine-picked cotton.

The machinery consisted of two stages of drying, cleaning, and extracting followed by the gin stands and two stages of lint cleaning.

Temperature control, typically, was from a pressure bulb located near the drier exit that controls gas input to the heater in an ON-OFF fashion.

Figure 2 illustrates the temperature gradients found in this type of drying system with ON-OFF temperature control.

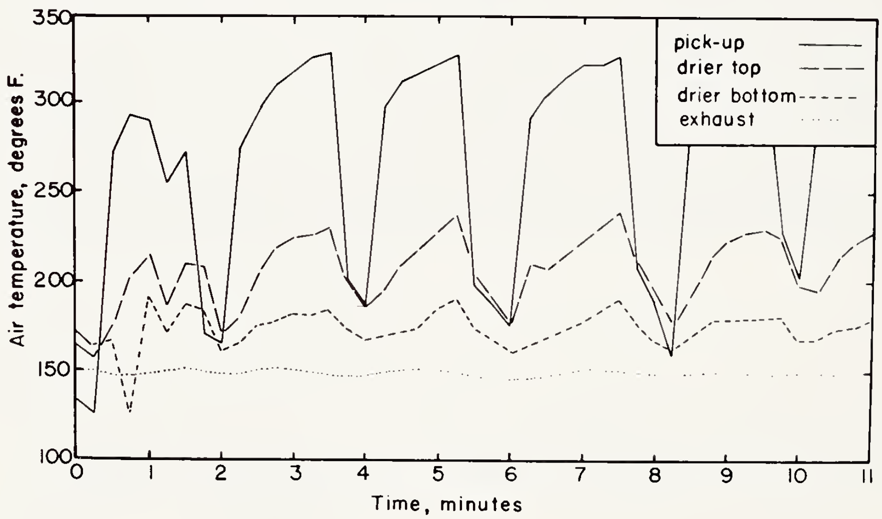


Figure 2. Temperature pattern in a seed cotton dryer using ON-OFF controller.

Even though the temperature at the control point is held within fairly close limits, the temperature at the drying system entrance varies from 325° to 160° F. and cycles at 2-minute intervals. This cycling rate to a large degree depends upon the heating and cooling rates of the pipe and drier itself and is somewhat modulated by the presence of cotton in the system.

In 1960 a resistance bulb controller operating a motorized gas valve became commercially available to ginners for controlling drier temperatures and may replace the ON-OFF controller. This unit should stabilize the temperature at the drying system pickup point quite well, if the sensing element is located at that point.

When the shelf-type cotton drier was developed in the late 1920's, the cotton crop was gathered by hand, with each day's picking going into a cotton house where the accumulated cotton tended to come to moisture equilibrium with the atmosphere. In those days, experimentation showed that drier

temperature of 160° F. was desirable for general use [3]. At that time the cotton conveyed directly from the wagon to the drier by ambient air was mixed with hot air at the top of the drier. This drier had 17 shelves spaced 15 inches apart. Temperature was measured at the top of the drier just before cotton and air mixed.

With the advent of mechanical harvesting and more complex ginning systems, gin drying systems assumed the additional functions of conditioning cotton for smooth flow through the gin and of enhancing the cleaning efficiency of cleaners. These gins separated cotton from unloading air and dropped it into the hot air line to the drier. As automatic bulk cotton feed controls were introduced, the hot air line was routed to pick up cotton as it left the bulk feeder. Thermometer bulbs were located somewhere near the bottom of the tower drier and heat input was adjusted to provide air temperature of 160° F. at this point. There is considerable temperature drop between the cotton pickup point and the lower part of the drier. Usually this drop is at least 100° F. and, in gins with long pipe runs, this figure may approach or exceed 200° F. on cool days. Thus, because of differences in gin plant layout, thermometer location, and other factors, particularly wide variations in moisture content of cotton received at the gin, the U. S. Cotton Ginning Research Laboratories have refrained, for several years, from stating temperatures recommended for drying cotton at gins.

In 1953, the Laboratory published "The important factor in the control of drying is the amount of moisture that is in the fiber when it finally reaches the gin stand. To that end, adjustments should be made in air temperatures to produce ginned lint having a moisture content of 5 percent or more . . . ."[4].

In April 1959, representatives from the Cotton Ginning Research Laboratories, National Cotton Council of America, and U. S. Department of Agriculture Extension Service met at Stoneville to consider recommendations for cotton harvesting and ginning for highest quality. This group agreed that for smooth ginning, proper cleaning, and optimum quality preservation, the ginning processes should be carried out with fiber moisture in the 5 to 7 percent range[5].

3/ "The Vertical Drier for Seed Cotton," by C. A. Bennett and F. L. Gerdes, U. S. Department of Agriculture Miscellaneous Publication 239. Issued April 1936, revised March 1941.

4/ "Drying Seed Cotton at Gins" - Review and Recommendations of U. S. Department of Agriculture Cotton Ginning Laboratory prepared by engineers and fiber technologists at the U. S. Cotton Ginning Laboratory, Stoneville, Mississippi, August 1953.

5/ "Report of Educational Conference - Workshop on Quality Cotton Harvesting and Ginning." U. S. Department of Agriculture Federal Extension Service, May 1959.

After the discovery in 1950 of the high correlation between fiber moisture content and fiber quality preservation, work was initiated: (1) To find a rapid method of fiber moisture content determination, (2) to explore the possibilities of and desirability of using vapor phase moisture restoration, (3) to determine the advantages and disadvantages of liquid phase moisture restoration to overdried cotton, and (4) to develop a system for controlled drying to deliver lint at a predetermined moisture content at the gin stand. One of the requisites for moisture restoration system was that it should operate concurrently with ginning and at the normal ginning rate.

MOISTURE RESTORATION

The vapor phase restoration work involved both steam and regain from controlled and uncontrolled atmospheres.

Steam pressure tests showed an average moisture increase of two percentage points after excess moisture evaporated. This was a batch process and deemed unsuited to gin plant use. In some of the continuous flow tests, steam proved to be a drying medium rather than a moistening agent.

Best restoration from controlled atmospheres was from high temperature-high humidity atmospheres. A pilot model moisture restoration unit operating at 90° F. and 94 percent R.H. (relative humidity) gave a fiber moisture change of from 3 to 7.2 percent in 1 minute. This work has been discontinued because controlled drying to predetermined fiber moisture levels offers a better end product than one heavily dried and returned to a higher moisture level[6/].

Liquid phase regain work showed that overdried cottons could be returned to high fiber property retention levels concurrently with ginning, but that some delay and agitation after spraying were required for adequate moisture distribution ahead of the gin stand. This work was discontinued when it was found that the efficiency of cleaning units following moisture restoration was seriously impaired. This work was done on single-lint-cleaner gins and showed lint foreign matter content of dried and sprayed cotton to be midway between that of the undried control lots and those lots dried and ginned without moisture restoration. The liquid phase restoration technique may be more satisfactory on gins with two stages of lint cleaning.

While the vapor and liquid phase restoration work was going on, a battery-operated, portable, resistance type meter, with sensitivity high enough to be of possible use as a moisture measuring instrument, was obtained. Early evaluation tests (1953) showed a fair correlation for lint moisture content between meter and oven determinations.

6/ "Excessive Drying and Fiber Damage," J. N. Grant and C. M. Merkel. Textile Bulletin, November 1958.

MOISTURE MEASUREMENT

The first attempt at continuous lint moisture gauging was in the lint delivery system of a 20-saw laboratory gin in 1954. The electrodes were thin brass cylinders placed so that the lint batt passed between them with the upper electrode "floating" on the batt. Even though this system was jury-rigged, it proved that an electrical signal proportional to moisture content could be obtained from a continuously moving mass of cotton.

The next year heavier electrodes were fabricated and installed in the three-stand gin plant. The signal electrode was composed of three 2-inch-wide aluminum bands on a wooden core, working against a grounded aluminum electrode. These electrodes rotate at a peripheral speed equal the linear speed of the batt moving from the lint condenser to prevent breaking the batt.

Tests using these electrodes showed that the effects of triboelectricity (static electricity) often overshadowed the desired electrical signal and would seriously interfere with proper operation of a controller if such a signal were used directly.

The Stoneville Laboratory undertook the design of a moisture detector that would be less sensitive to unwanted electrical signals and whose output could be coupled to a recorder-controller.

In the meantime, other work under this investigation showed that seed cotton moisture response was good, but somewhat less reliable than that of lint. Moisture content of cottonseed and foreign matter introduces some error, but fiber moisture remains the prime factor being measured.

The laboratory-built detector tested at Stoneville was a rather complex affair that was difficult to adjust and calibrate. Two of these units were constructed and placed in the drying system--one in the feed control hopper and the other at the drying system exit. This system was demonstrated at the Clemson Ginning Research Laboratory in 1959, where the two sensors showed differences attributable to fiber drying.

EFFECT OF EXPOSURE

For a number of years laboratory researchers noted that in some drying tests the ginned lint moisture content often fell within a relatively narrow range, even though there was considerable variation in initial fiber moisture levels. This was especially true when drying at the higher temperatures where readily available (surface) moisture was quickly evaporated.

Since any controlled drying system must be based on drying rates, a study was designed to implement the meager knowledge of specific gin drying rates. The drying system was a 300-foot length of 16-inch-diameter pipe. Cotton feed rates and air volumes closely approximated those in commercial gins. Inlet drying air temperature was 285° F. Sampling stations were provided at 20-foot intervals along the pipe for extracting seed cotton for immediate ginning and fiber-moisture determinations. Comparison of the initial cotton moisture content with that from the sampling stations showed a great change in the first 3 seconds of exposure, with relatively little change after that.

The very rapid drying rate revealed by these tests and the logarithmic shape of the falling rate drying curve explain why lint moisture contents may be similar after drying even though input moisture levels vary. This is more pronounced when using high drying temperatures and long drying exposures so that the system works further along the flat portion of the drying curve (Fig. 3).

Figure 3. Typical falling rate drying curve.

Due to the short period required to remove moisture to the recommended ginning level of 6 percent, the decision was made to attempt drier control by controlling the exposure period while keeping the drying air temperature at a fixed level.

CONTROLLED EXPOSURE DRYING

In 1960, the Stoneville Laboratory developed a three-path drier (Fig. 4) so that cotton could be introduced at three locations to provide three exposure periods[7]. Due to the temperature gradient of the system, cotton is also exposed to a different initial temperature for each drying

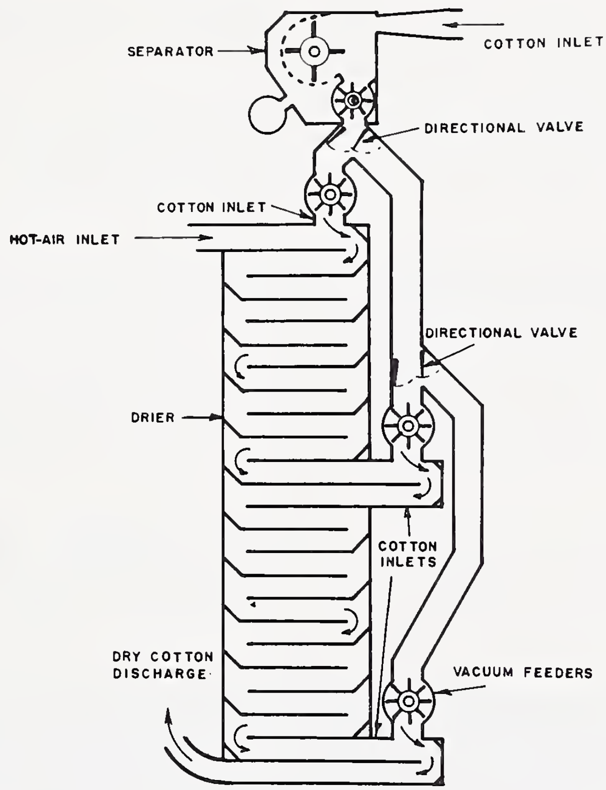


Figure 4. Sectional drawing of 3-path drier for automatic exposure control.

path. A pre-selected, fixed temperature is maintained at the top of the drier by a temperature controller resistance bulb installed at that point. Tests showed exposure periods of 10, 6, and 2 seconds for the long, moderate, and short drying paths, respectively. Using 350° F. as the fixed temperature for the long, moderate, and short drying paths, cotton was exposed to initial temperatures of 346°, 315°, and 272° F. With 250° F. as the fixed temperature, initial exposures for the three drying paths were 244°, 227°, and 203° F. For the 350° input temperature, exhaust temperature was 185°. For the 250° temperature, exhaust temperature was 144°.

7/ "Progress Report, Multi-Path Drier Development," by G. N. Franks and C. S. Shaw, The Cotton Gin and Oil Mill Press, June 24, 1961.

A series of 36 three-bale tests was run to determine the drying limits of the system. The season's average produced lint at the press of 5.5, 4.8, and 4.3 percent moisture content for the 350° F. tests, and 6.3, 6.0, and 5.5 for the 250° F. tests. For the damper cottons, a two percentage point spread between long and short drying paths was demonstrated.

SEED COTTON FIBER MOISTURE MEASUREMENT

While the drying tests were going on, other tests were conducted to establish a tentative calibration of the continuous electronic moisture detection system and to use the moisture level signal to select automatically the drying path through the experimental drier.

For this work, a commercial instrument was used as the moisture detector. It has high stability and ease of adjustment that was not present in the laboratory-built units. This detector circuit, when used with 50-inch rotating electrodes, gives a 0-10 millivolt output over a wide range of fiber moisture levels, with good resolution between about 4 and 14 percent fiber moisture. More specifically, the detector system at Stoneville measures the electrical resistance of seed cotton passing between two rotating electrodes as an index to fiber moisture content.

Eleven tests using cotton of different moisture levels were used for preliminary testing. Some of these had been artifically wetted to provide damper cotton than was being received at the gin. The relationship of detector response versus fiber moisture content is shown in figure 5. Initial inspection of the scatter diagram showed more scatter than was anticipated and raised the question, "Is this relationship good enough?" After identifying the rewet cotton data and encircling those points, the data for cotton that had not been rewet looked much better and the trend line was drawn in by inspection. Now the artificially wet cottons are displaced to the right of the trend line for cotton containing natural moisture except in the 12 percent and higher range, where they seem to fit very well.

THE CONTROLLED DRYING SYSTEM

The three-path drier lends itself well to a control system since the paths can be changed simply by throwing directional valves. The stripchart recorder uses a servomotor to position the recording pen. It was a simple matter to install cams and snap-action switches on the motor reduction gear hub and bracket (Fig. 6). The snap-action switches energize solenoids in the pilot valves that actuate the pneumatic cylinders and operate the directing valves (Fig. 7). The switching cams are held by friction nuts and can be positioned easily to trip the gate valves at any setting along the trend line which now becomes the operating curve.

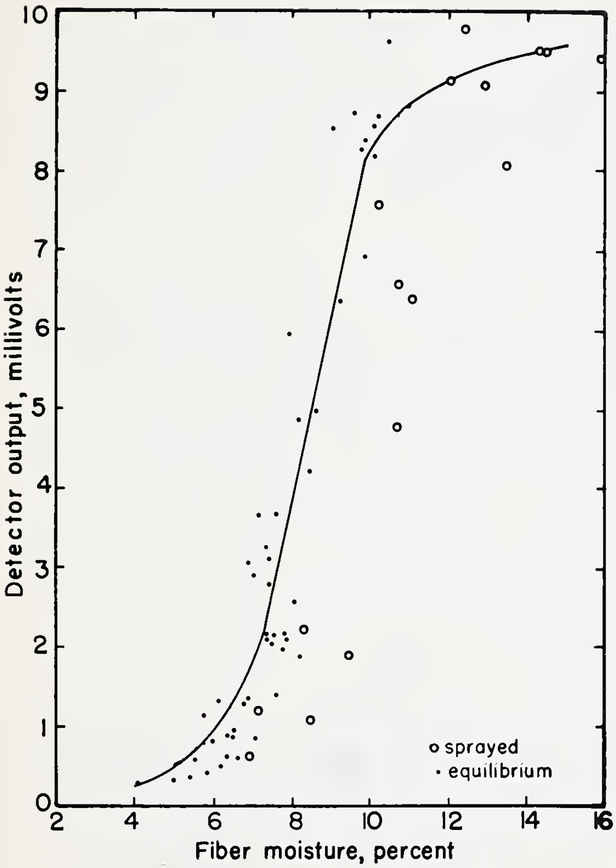
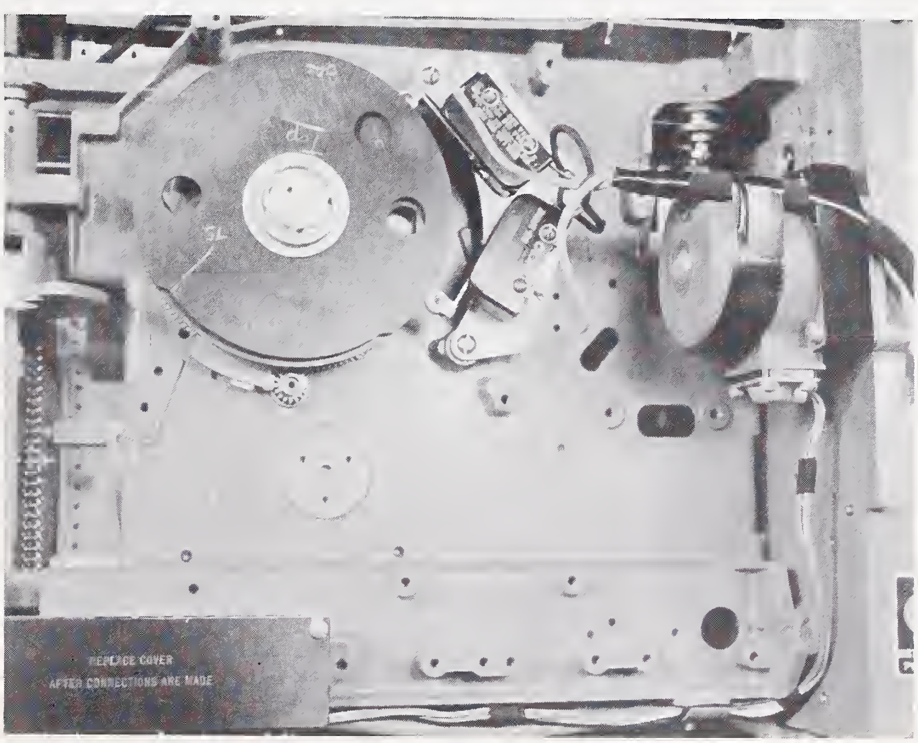


Figure 5. (Left) Moisture detector output as a function of fiber moisture content.

Figure 6. (Below) Cams and snap action switches on pen positioning gear hub for controlling cotton drying through 3-path drier.



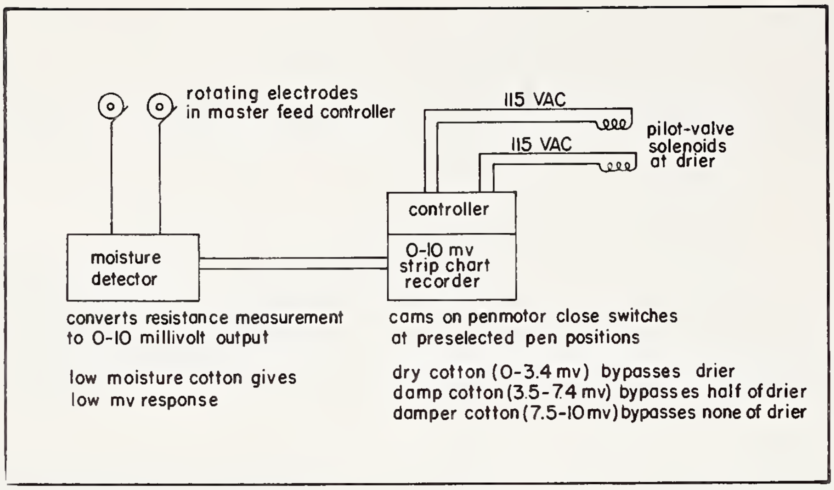


Figure 7. Major elements of the automatic drying control system at Stoneville, Miss., 1960-61.

AUTOMATICALLY CONTROLLED DRYING TESTS

In February 1961, two series of tests were run with the combined system under fully automatic control. No operating difficulties of any kind were encountered. The first of the full-automatic tests was run, using lots of storage and rewet cottons. These lots were fed alternately to the feed control hopper without permitting the hopper to become empty between lots. The system automatically changed the drying path as the detector sensed changes in moisture content. Incoming moisture content was 9.4 percent for the storage lots, and 11.9 percent for the rewet lots; lint slide moisture levels were 5.0 percent and 4.6 percent, respectively. Control point temperature was 340° F.

The second test was made on alternate lots of cotton directly from storage and on previously dried cotton. Again, lots were alternately fed to the feed control unit without permitting the hopper to empty itself between lots. Initial fiber moisture levels were 8.6 and 4.2 percent for the undried and dried lots, respectively, producing fiber moisture levels at the lint slide of 3.8 and 4.2, respectively. Control point temperature for these tests was 250° F.

PROBLEMS AND FUTURE WORK

Much work remains to be done. The problems of trouble-free measuring electrodes must be solved. In the system just described, the measurement is made on cotton between two separate electrodes, one of which is grounded. The other electrode must be insulated thoroughly from the hopper wall to

prevent current leakage paths and erroneous readings. At present, the use of a multi-band electrode, where an optimum number of conducting bands may be put on an acrylic core and alternately connected as "hot" and "ground", is being investigated. In this case, the measurement would be between adjacent bands. To develop a standard electrode that could be used readily in any resistance measuring system and that would fit into any make of cotton gin plant is one of the final objectives of this work.

At the time moisture measurements are made, cotton often contains sizable quantities of foreign matter, particularly plant parts and grass. The moisture content of these elements renders them conductive and causes error in fiber measurement.

Recent work has shown the location of fiber moisture to cause deviations in the recorded signal (Fig. 8). It has been noted that surface moisture

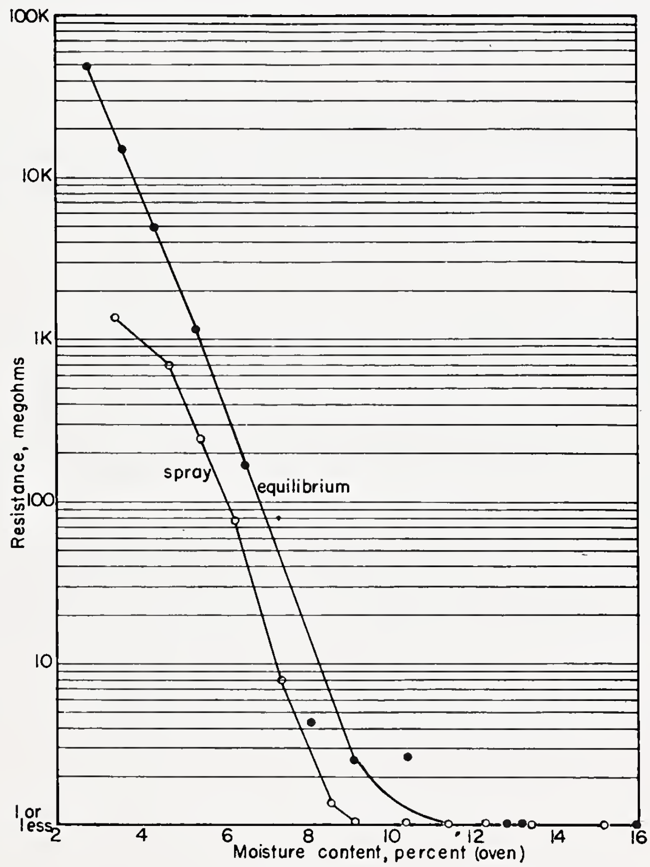


Figure 8. Effect of fiber moisture location on resistance of cotton fiber.

as applied by an insect spray gun indicates a damper cotton, because of its lowered resistance, than cotton of similar moisture content from an equilibrium atmosphere. This situation would contribute to over-drying because the instrument would demand more drying for surface wet cotton than necessary.

The effects of electrode areas and pressures have been investigated to some extent. So far as pressure on the cotton is concerned, after a critical pressure has been reached, the resistance curve begins to flatten out so that further pressure increases are not so significant as they are before the critical pressure is reached. In 1960, the possibility of rod type electrodes protruding into the cotton hopper was explored and it was found that variations in pressure due to the quantity of cotton in the hopper caused erroneous meter deflections.

Work done in 1955 by the senior author, and recently repeated, shows that the general law of electrical resistance ($R = p\frac{l}{A}$) does not seem to hold for measuring the resistance in cotton batts in gins without correction coefficients. Empirical tests will be used to determine electrode areas for this application rather than experiments to discover the correction values.

Other problems have to do with closing the control loop and investigating other methods of drying control. The present system is an open loop system--that is, there is no measuring system after drying to feed back into the controller as a correction if the drying accomplished was too much or too little.

Varying the drying air temperature is a likely method for trial since there are many temperature controllers already on the market. This also might be a good time to take a look at present gin driers with the intent of developing more efficient and more readily controlled driers than those now on the market. There is a strong trend to increase hourly ginning capacities; the drying system must be capable of keeping pace with 20-bale-an-hour ginning rates.

It is not unreasonable to expect that a moisture restoration unit be linked to the control system to raise the moisture level of cottons harvested during periods of low humidity. This work is in the planning stage.

Another problem that will receive early attention is the control of two-stage drying from a single moisture measurement.

Growth Through Agricultural Progress